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955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

SUBJECT: Summary Description of Outer Planet Grand Tour Missions - Case 103

DATE: December 26, 1968

FROM: A. A. VanderVeen

ABSTRACT

Presented here is a brief summary of the characteristics of "grand tour" missions to the outer planets. Five mission opportunities are available from 1976 through 1980; however, in 1976 Jupiter passage distance is marginal and trip durations are longer, and in 1980 launch velocities are highest. Launch windows, the Jupiter swingby effect, and guidance requirements are discussed.

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MEMORANDUM FOR FILE

Introduction

There appears to be a rather general impression that "outer planet grand-tour" missions utilizing a Jupiter swingby are available only in 1977 and 1978 in the current time frame. It is reported by H. S. London, e.g., that many of the attendees of the STAC Winter Meeting* were of this belief. This memorandum briefly discusses the general characteristics of such missions and their range of opportunities. The reader is referred to References 1 and 2 for a more comprehensive treatment of the subject.

Background

A planetary swingby is defined here to be a close approach to a planet in order to favorably perturb the trajectory to another planet. A planetary flyby, on the other hand, is a close approach to a planet primarily for purposes of reconnaissance.

The "grand tour" missions are comprised of successive close approaches to Jupiter, Saturn, Uranus, and Neptune--the Jovian planets. These unpowered flights are practical, according to Silver[1], only for specific planetary configurations when trailing-edge passages of each planet can be made, thereby increasing the heliocentric energy of the trajectory as each encounter is accomplished. The desired configuration of the planets occurs only once every 179 years with the next opportunity occurring during the late 1970's. However, since these "outer" planets move relatively slowly in their respective orbits, their relation to each other remains generally intact for several years, and hence a number of launch

*NASA Science and Technology Advisory Committee Meeting at La Jolla, California, December 6-9, 1968.

opportunities from earth occur, at intervals determined by the synodic period of Jupiter with Earth - 13 months, approximately.

It should also be noted that, as Silver points out, grand tours which skip Jupiter (Earth-Saturn-Uranus-Neptune) should be available for some years after 1980, although higher launch velocities would be required than for the complete mission.

Importance of the Jupiter Swingby

Assuming that the appropriate configuration of the planets exists, reasonable-energy grand tour trajectories are heavily dependent upon the Jupiter swingby effect. Even though Jupiter's mean density is less than one-fourth that of earth its enormous size makes it a strong center of gravitational attraction. The trailing-edge encounter in 1977, for example, increases the spacecraft's heliocentric velocity by 11 km/sec (36,000 fps). Deerwester[2] describes in detail the Jupiter swingby effect applied to a mission to Uranus in 1978. Even for relatively high approach speeds a close approach produces a large turn angle, e.g., approximately 115° in 1978. The spacecraft emerges from the planetary encounter with a heliocentric velocity of more than twice Jupiter's orbital velocity and almost in the same direction. Thus, the encounter imparts sufficient energy to the spacecraft for an escape from the solar system.

The Grand Tour Opportunity

Silver provides tables and graphs illustrating the characteristics of grand tour missions available from 1976 through 1980--five opportunities. In 1975 Jupiter has not yet moved into good position in relation to Saturn, and in 1981 Jupiter has moved ahead too far for the probe to "pick up" additional heliocentric energy from Jupiter, so these bounding cases are of only marginal utility. However, for each of the remaining five opportunities there is a 2-to-3 week launch window available, and some latitude exists in the planetary passage distances or passage dates. Launch dates differ by a few days if interior rather than exterior passages of Saturn's rings are considered, and both classes are investigated in equal detail. For either interior or exterior passage of the rings, launch characteristic velocity is lowest in 1976 and increases monotonically through 1980. Minimum velocities go from about 49,000 fps to 57,000 fps for interior passage, and from about 47,000 to 54,000 fps for exterior passage. Jupiter passage radius appears to

be marginal in 1976 ($\sim$ 1.02 Jupiter radii for interior passage of Saturn's rings, 1.5 for exterior passage) but increases substantially in the succeeding opportunities. Trip times are lowest in 1978 through 1980 (approximately 8 years for interior passage and 11 years for exterior passage), and are about one year longer in 1977 and two years longer in 1976.

Guidance

Friedlander[3] discusses guidance requirements for grand tour missions considering separately radar tracking and on-board celestial navigational modes. He considers interior and exterior Saturn ring passages in both 1977 and 1978 and finds that celestial tracking can reduce the guidance ΔV requirements by factors of 2 to 4, that interior ring passages approximately double the guidance requirements over exterior ring passages, and that in any case 8 to 10 corrective maneuvers will be required. He concludes that while the guidance requirements for grand tour missions are more severe than for current by envisioned planetary missions, they are not beyond the present or projected state-of-the-art. A strong case is made for an on-board celestial tracking capability.

Summary

Grand Tour missions to the outer planets are available at 13-month intervals from 1976 through 1980. These opportunities rely heavily upon the Jupiter swingby effect, and the appropriate configuration of the planets involved will not present itself again for another 179 years.

Adequate launch windows and moderate launch energies are characteristic of each mission opportunity, and trip durations to the outer planets are drastically reduced by the Jupiter swingby over comparable-energy Hohmann transfers.

Guidance requirements for grand tour missions appear to be within the present state-of-the-art.

for AA VanderVeen

1013-AAV-nma

A. A. VanderVeen

Attachment
References

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1. Silver, B. W., "Grand Tours of the Jovian Planets," AIAA Paper No. 67-613, AIAA Guidance, Control and Flight Dynamics Conference, Huntsville, Ala., August 14-16, 1967.

2. Deerwester, J. M., "Jupiter Swingby Missions to the Outer Planets," AIAA Paper No. 66-536, AIAA 4th Aerospace Sciences Meeting, Los Angeles, California, June 27-29, 1966.

3. Friedlander, A. L., "Guidance Analysis of the Multiple Outer Planet (Grand Tour) Mission," AAS Paper No. 68-109 AAS/AIAA Astrodynamics Specialist Conference, Jackson, Wyo., September 3-5, 1968.

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